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Premature Failure of Deep Well Anodes

THOMAS F LEWICKI

DETACHMENT 1

JUNE 1978

FINAL REPORT FOR PERIOD
DECEMBER 1975-MAY 1978

Approved for public release; distribution unlimited

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CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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This report covers an investigation into the causes of premature failure of deep well anode beds. Anodes or lead wires were retrieved from two failed deep well anode beds and analyzed. Deep well conditions were simulated in the laboratory and graphite and HSCI anodes were subjected to different electrolytes and normal current outputs. A new wire insulation was tested and compared to HMPE insulation under deep well conditions in the lab.

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PREFACE

This report summarizes work on premature failure of deep well anodes done between December 1975 and May 1978. Mr Thomas F. Lewicki, P.E., was principal investigator for AFCEC on this work. The work was done in-house, the majority of the research being accomplished by the author. In addition, the principal investigator wishes to acknowledge the following persons for their contributions of assistance or data during the course of the research: Mr Harold Stevens, P.E., of AFCEC, chemistry theory and technology; MSgt James Griffin, technician, of CEEDO, construction and operation of laboratory test apparatus; and Mr Al Purer, Chemist, Naval Coastal Systems Laboratory, analysis and identification of anode gases. Work was accomplished under the supervision of Mr A. Stanley Dalton, P.E., Director of Engineering Materials, Air Force Civil Engineering Center (AFCEC).

This report is designed for use by base and Command Corrosion Engineers to enhance their understanding of the advantages and shortcomings of deep well anode beds and to assist them in designing longer-lasting deep well anode beds.

This technical report has been reviewed and is approved for publication.

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SECTION I

BACKGROUND

A. INTRODUCTION

Deep well anode beds have several important advantages over conventional surface-type ground beds. Some of these advantages are: (1) deep wells do not need large open unpaved land area, (2) uniform current distribution along a long pipeline is much better, (3) less interference is caused to other structures, and (4) lack of ground moisture is never a problem. Two of the disadvantages of deep well anode beds are: (1) they are more costly to install and (2) they often fail prematurely. The exact cause of premature failure is, in most cases, unknown. There has been much speculation as to the probable cause, but examination of the failure is almost never made because of the expense and uncertainty of success in retrieving anodes and cable from wells that have been backfilled. Most wells are backfilled with coke breeze (powered coke) within the anode area and gravel above the coke breeze.

Recently, a patented method has been devised that allows easy replacement of failed anodes. This is not the optimum solution since this method is more costly than conventional deep well anode beds and each replacement means additional costs and cathodic protection down time.

Our objective in this project was to determine the cause or causes of premature failure and to recommend corrective action with the ultimate goal of achieving reliable, long life deep well anode beds.

For many years, industry has been working to find the cause of premature failure of deep anodes. Their efforts had been documented in a committee of the National Association of Corrosion Engineers. They did not meet with success and the committee is no longer active.

B. BACKGROUND INFORMATION

The Air Force has several deep well anode beds that have failed prematurely. Premature failure is considered to have occurred when the resistance-to-earth of the anode bed has increased to a point where it is less costly to replace the ground bed than it is to continue to pay the high power bill, or when the required current can no longer be maintained. Since output power is $I^2 \times R$, power consumed is directly proportional to circuit resistance. It was our intention to have anodes and lead wire retrieved from two failed deep well anode beds by contract.

A synopsis of the work to be done by contract was entered in the Commerce Business Daily with hopes of obtaining a contractor to retrieve anodes and lead wire from a 250 ft well at Barksdale AFB LA and a 225 ft well near Little Rock AFB AR. Both wells had been backfilled with coke breeze to a point above the top anode and the well at Little Rock had been backfilled from the top anode to the surface with one to two inch diameter gravel (50 ft). No contractor was willing to submit proposals to do this work, so the Civil Engineering Center decided to accomplish the work themselves (in-house).

HQ SAC stipulated that we could retrieve failed anodes at Barksdale AFB and Little Rock AFB only if we replaced failed anodes with new anodes, since they needed working ground beds at both of these places to provide cathodic protection. Of the 11 anodes originally installed at Barksdale, the bottom 7 anodes had failed (zero current output) by October 1975.

The anodes were originally installed in 1967 but not operated until the rectifier was installed in May 1969. In April of 1976 the eighth anode had failed but this was not the eighth anode from the bottom. It was the tenth from the bottom. Anode No. 8 and 9 were still operating. The anodes started failing shortly after installation, the lower anodes failing first.

The deep well anode bed at Barksdale AFB consisted of an 8-inch diameter hole drilled to a depth of 250 feet. The original installation was completed in October 1967. Twelve high silicon chromium bearing cast iron ("Durichlor"), type "D" anodes were installed between the 245 foot and the 163 foot level measured from the ground surface. The well was backfilled with coal coke breeze, passing a 1/8" sieve, from the bottom of the hole (250' level) to the top of the highest anode (158' level). All anodes had individual #8 lead wires insulated with high molecular weight polyethylene (HMPE) insulation. A 1-1/2 inch polyethylene pipe with holes drilled along the anode area was installed as a vent pipe to allow anode gases to escape. Initial circuit resistance, of which the ground bed is the major portion, was 0.43 ohms. The circuit resistance in May 1976 just prior to replacement of the anodes was 2.1 ohms with only 4 of the 12 anodes still functioning.

The deep well north of Little Rock AFB consisted of a 225 foot deep, 10 inch diameter hole that was drilled through mostly shale and sandstone. This well has had a continuous artesian flow since the time it was drilled. The anodes in this well were installed in 1968. The resistance to earth of the anodes at the time of installation is not known because no current output was allowed until a study was completed to reveal any possible detrimental effects to electrical systems of the missile or related support components. The initial turn-on of rectifier current did not occur until 1970, two years after installation. Initial operation of this ground bed revealed that anode-to-earth resistance was very high.

SECTION II

RETRIEVAL OF FAILED ANODES AND ANODE LEAD WIRE

A. BARKSDALE AFB LA

A military team from the field activities branch of the Civil Engineering Center arrived at Barksdale AFB LA on 16 June 1976 for the purpose of retrieving failed anodes and lead wire from a 250 foot deep well. The well contained 12 anodes spaced as shown in Table 1. The three foot diameter steel plate welded to a short piece of 8" casing that served as the well cap was removed. No gravel was found in the top of the well. Eight feet below ground level the well was filled with what appeared to be the original red clay. The clay in the well was fluidized by pumping drilling mud down the hole through 1-1/2 inch pipe fitted with a special point. The point had two holes drilled into it at a 45^{o} angle so as to make the high pressure drilling mud effective in fluidizing and enlarging the backfilled hole. Working the 1-1/2 inch mud pipe into the hole went fairly easily. A total of 147 feet was fluidized during the first day (See Figure 1). Progress through the coke breeze was much slower. The mud viscosity was 48. At the end of the second day of work, the bottom of the well was reached (251 ft). We tried pulling the anode lead wires as a bundle and individually but none of the anodes would move. During the third and fourth days, we pumped mud at high pressure (400 to 500 PSI) while working the 1-1/2 inch mud pipe up and down the well. We also introduced blasts of air from a large compressor (115 PSI) down the hole through the mud pipe. Finally, with nothing left to do, we pulled the wires. All wires broke at various depths. Wire No. 1 broke 15 feet from the surface. Examination showed that the insulation had been damaged and the copper conductor had corroded in two. Wire No. 3 had been burned by the torch of the welder who cut open the well cover. Several of the wires had been damaged by the 1-1-1/2 inch mud pipe. The length of wire No. 4 retrieved was 216 ft. This means that it separated near the top of anode No. 4. The bottom end of this wire showed complete deterioration of the high molecular weight polyethylene insulation. The insulation turned white in certain areas, cracked and necked down until the copper was exposed and corroded to failure (Figure No. 2). Figure 3 shows the deteriorated insulation magnified by 10. It is obvious from the examination of the deteriorated insulation of Wire No. 4 that No. 4 anode failed because the copper conductor corroded in two after the insulation deteriorated. It is reasonable to assume that the other seven inoperative anodes failed either from mechanical damage to the lead wire insulation or from deteriorated insulation.

B. LITTLE ROCK AFB AR

From Barksdale AFB, the AFCEC team traveled with their equipment to the deep well anode bed site located at a missile site north of Little Rock AFB, AR. Table 2 shows the position and depth of the original design of the anodes in the 10 inch diameter hole. The 5 ft

TABLE 1. FINAL ANODE LOCATION AND RESISTANCE
ORIGINAL DEEP WELL GROUND BED BARKSDALE AFB, LA

Tested 19 Oct 1967

Anode No.	Depth Measured From Bottom of Anode (ft)	Individual Anode Resistance* (Ohms)
1	245	6.5
2	235	3.1
3	228	6.3
4	221	6.9
5	212	6.3
6	205	3.3
7	198	3.8
8	191	3.9
9	184	4.4
10	177	5.1
11	170	2.6
12	163	3.0

*Total circuit resistance = 0.43 ohms

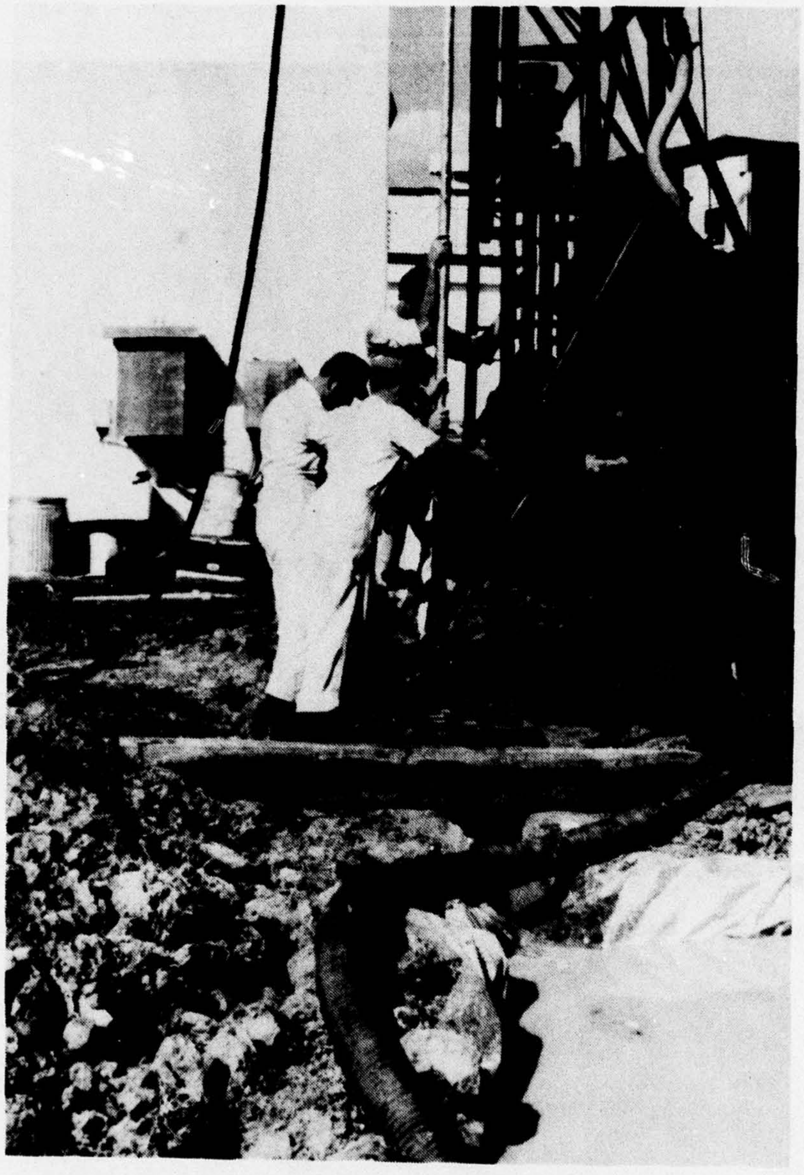

Figure 1. Fluidizing Clay in the Well

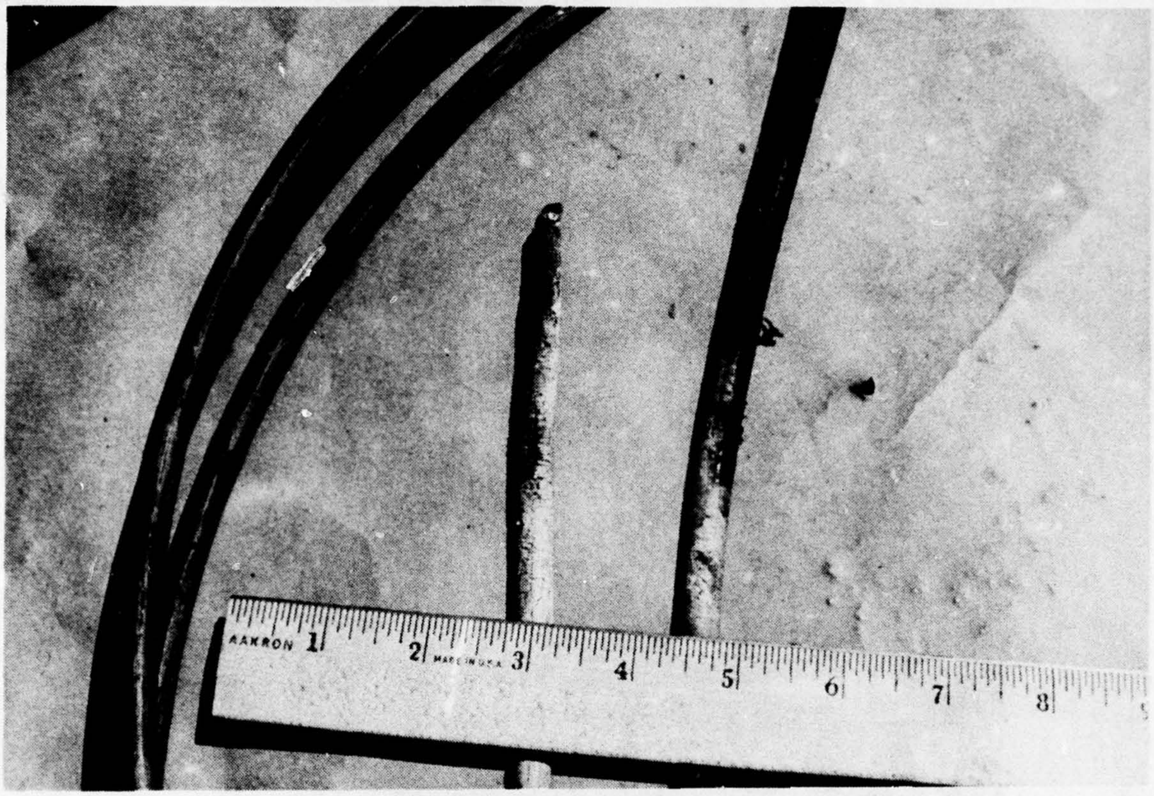

Figure 2. Deterioration of Insulation on Wire No. 4

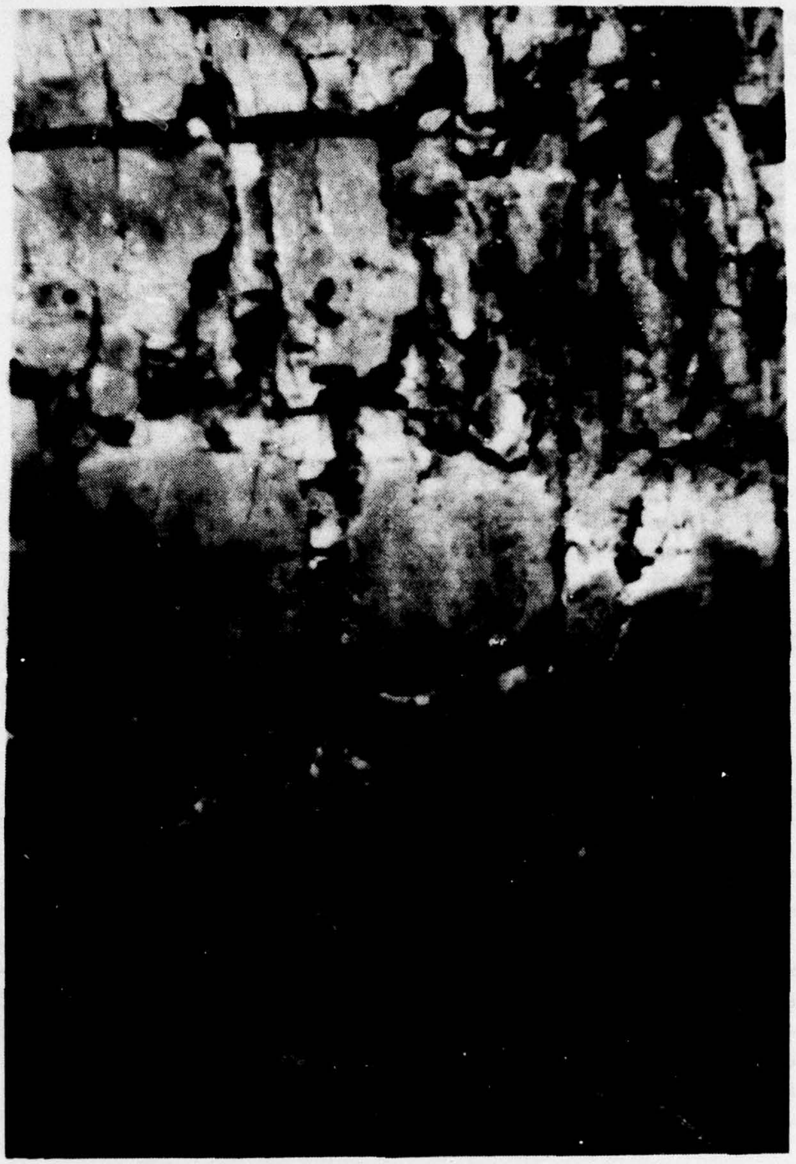

Figure 3. Deteriorated Insulation Magnified By 10

long high silicon cast iron (HSCI) anodes were strapped to a 1-1/2 inch steel pipe in pairs as shown in Table 2. No anodes were located between the 80 ft and 170 ft depth because of high resistance sandstone in that area.

Prior to choosing this well to extricate anodes, current measurements were made to determine the output of each anode. With 37 volts applied, the current output was very low. Individual anode currents and calculated anode-to-earth resistances are shown in Table 3. The total anode bed resistance-to-earth is considered much too high for economical operation and adequate protection of the facilities could not be obtained. For these reasons this deep well anode bed was considered to have failed. Individual anode resistances were all considered to be unusually high.

This well was supposed to have been backfilled with coke breeze from the bottom of the well (225 ft) to the 40 ft level which was 5 feet above the top of the highest anode. Above the coke breeze the well was backfilled with large gravel from the 40 ft level to the ground surface.

The well drilling machine was set up over the well and an effort was made to fluidize the backfill in the well similar to what was done at Barksdale AFB. Mud viscosity had to be increased above 500 in order to float out the large gravel. Pump pressure was raised as high as 500 to 550 psi. The entire column of 40 ft of large gravel was successfully removed by fluidizing with thick mud. Gravel as large as 2 inch diameter (Figure 4) was floated to the surface. After the fluidizing pipe reached the 80 ft level, 5 anodes were easily removed. Two of the five anodes had broken approximately 1/4 of the way from their bottom end (Figure 5); the other three anodes appeared to be in like new condition.

It has been suggested that the film of silica (SiO_2) that always develops on the outside of a HSCI anode can, under certain conditions, become a high resistance film. There was no evidence of this in this case. As soon as the anodes were extracted they were carefully examined. Visual examinations showed no visible oxide film. An electrical continuity test between the top end of the lead wire and the anode body showed almost zero resistance. When the anodes were placed in a water filled tub in the laboratory with a small voltage applied, current output was high, indicating low resistance between the anode and the water. Resistivity of the water in the lab test was 6800 ohm-cm whereas the resistivity of the water in the well at Little Rock is 6200 ohm-cm. It is the author's opinion that the only cause for such low current output was gas blockage between the anode and the coke breeze. Figures 6 and 7 show sections of the anodes where the worst corrosion damage occurred.

In addition to the 5 anodes, the following items were retrieved from the anode bed (referring to Figures 8 and 9).

TABLE 2. ORIGINAL DEEP WELL ANODE INSTALLATION,
LITTLE ROCK AIR FORCE BASE, ARKANSAS

GRADE (FT.)	ANODE NO.&SPACING	
0		
10		
20		
30		
40		
50	19	20
60	17	18
70	15	16
80	13	14
90		
100		
110		
120		
130		
140		
150		
160		
170	11	12
180	9	10
190	7	8
200	5	6
210	3	4
220	1	2
230		

TABLE 3. ANODE TESTS DEEP WELL NO. 2, LITTLE ROCK AIR FORCE BASE, ARKANSAS (37 Volts Applied) 2.2 AMP TOTAL

ANODE NO.	CURRENT OUTPUT (MA)	RESISTANCE (OHMS)
1	60	616
2	50	740
3	60	616
4	70	529
5	140	264
6	70	529
7	130	284
8	130	284
9	20	1850
10	30	1233
11	130	284
12	30	1233
13	220	168
14	210	176
15	90	411
16	180	205
17	160	231
18	170	217
19	90	411
20	160	231

Figure 4. Large-diameter Gravel Floated Out of Well

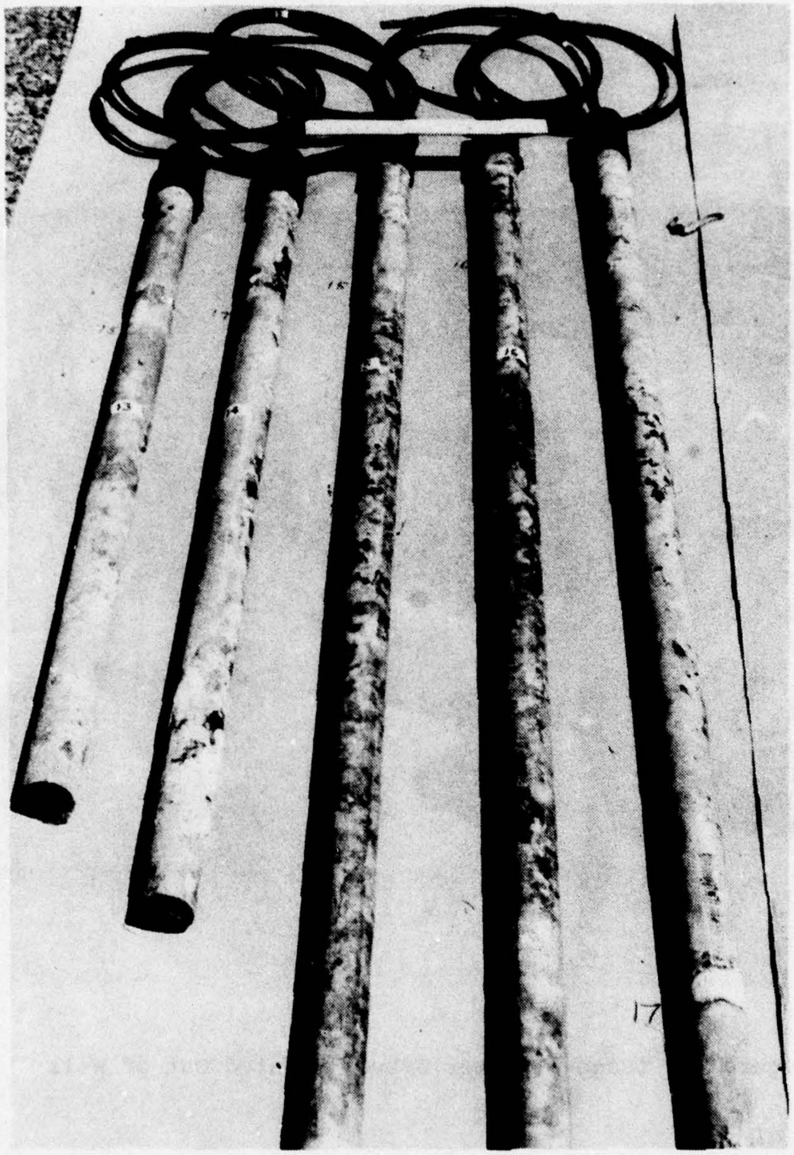

Figure 5. Anodes Taken From Well

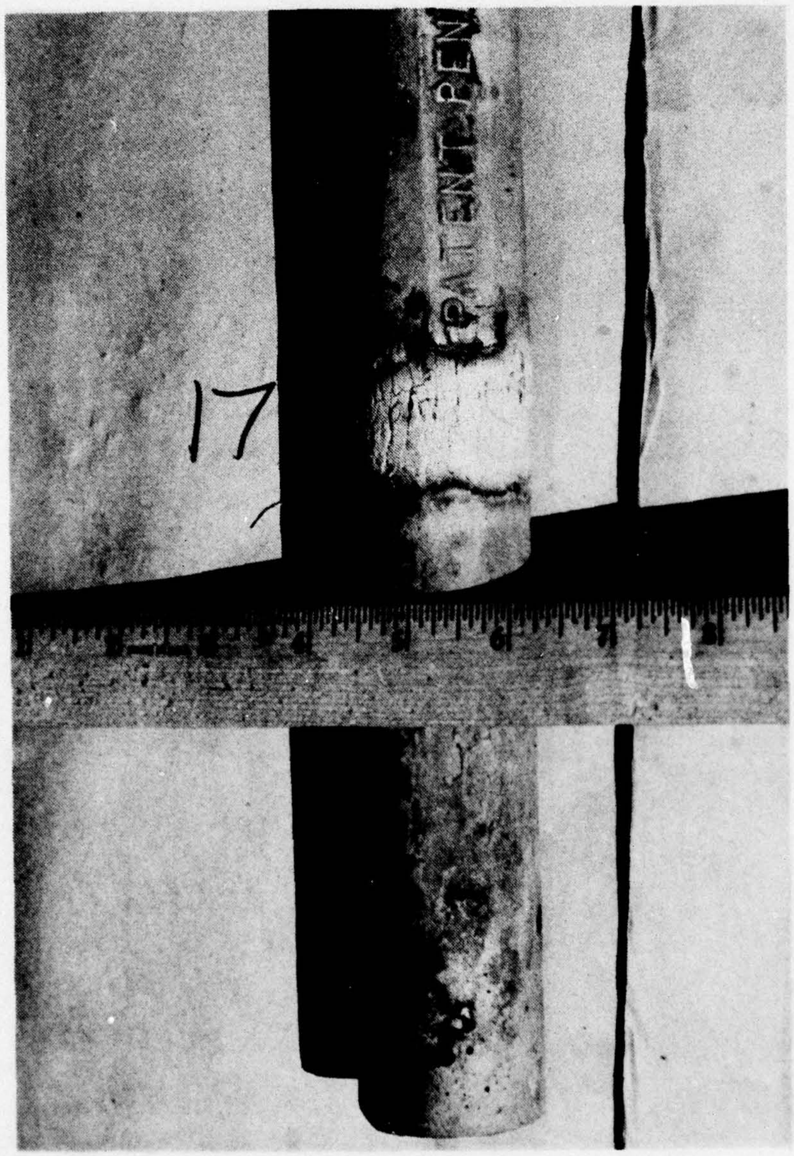

Figure 6. Corrosion Damage

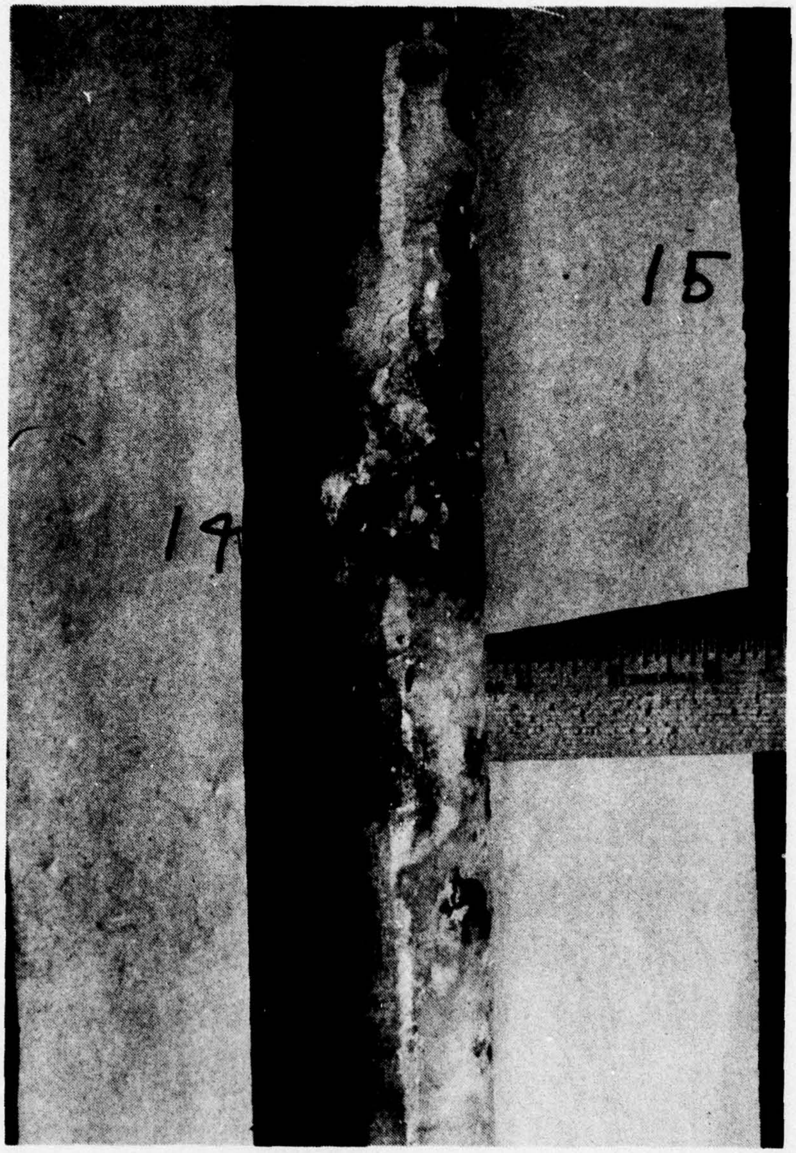

Figure 7. Worst Corrosion Damage Found at Little Rock AFB

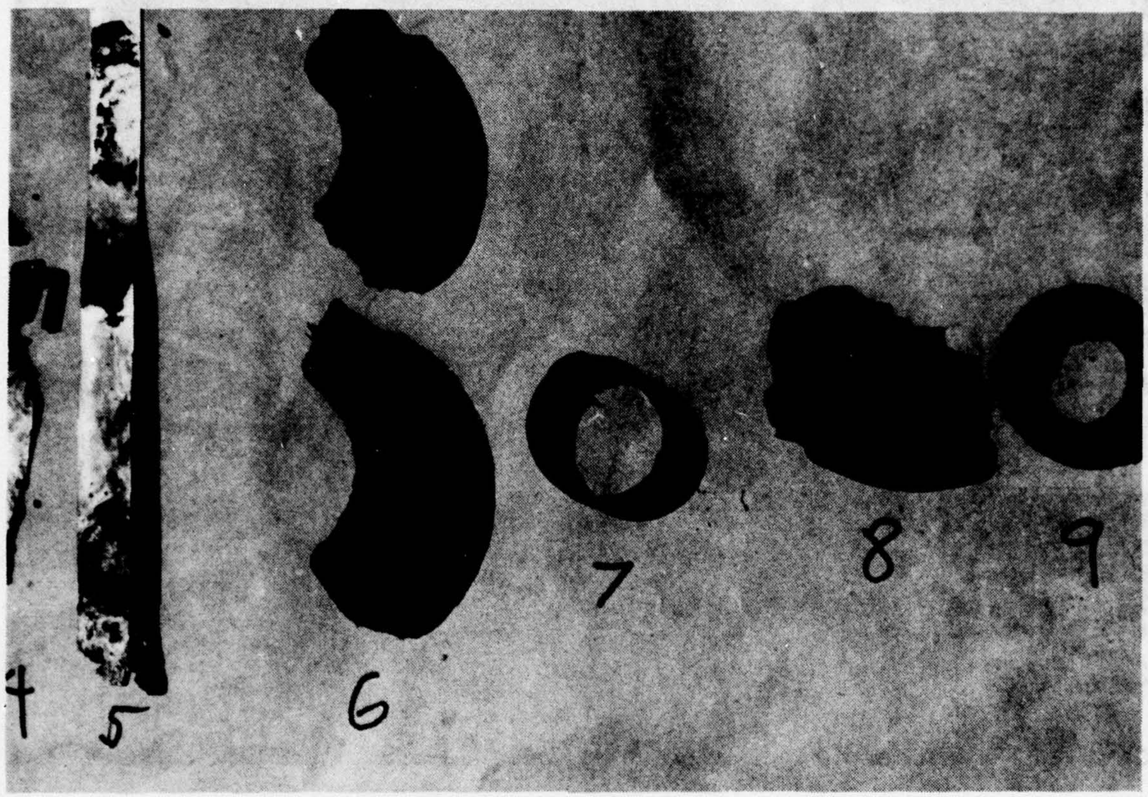

Figure 8. Items Retrieved From Anode Bed

Figure 9. Technician Holding Flattened Plastic Vent Pipe

a. In Figure 8 from left to right, stainless steel bands that held anodes to support pipe, wooden spacers that were placed around anodes, plastic insert from insulated union (7), parts of an insulated union with most of the steel corroded away (8 and 9). These parts were designed to hold the anodes only until the backfill was in place and their deterioration is to be expected.

b. In Figure 9, a technician is shown holding a flattened 1-1/2 inch plastic vent pipe. This pipe had holes drilled in it throughout the area where anodes were installed. The top 15 feet of the vent pipe was normal but below that point the pipe gradually flattened and below the 20 ft level the plastic pipe had been squeezed completely flat. It is suspected that the coke breeze plugged the holes in the plastic pipe and the pressure of the water and coke breeze flattened the pipe. This indicates that vent pipes are not effective unless the minimum particle size of coke breeze is larger than the holes in the pipe.

SECTION III

INSTALLATION OF NEW TYPE ANODES

At Barksdale AFB and Little Rock AFB, new chromium bearing high silicon cast iron anodes were installed to replace the failed anode beds. The anodes were type TA-3, tabular, 2-21/32 inch diameter, 84 inch length with the lead wire connection within the center of the hollow anode. The anode lead wires were insulated with 20 mils of Halar© fluorcopolymer and an outer jacket of 65 mils of HMPE insulation. In addition, each anode had an auxiliary support device, consisting of a radiation crosslinked polyvinyldene floride (Kymar©) rope from which the anode was suspended.

At Barksdale, a new well was drilled to a depth of 250 feet and the anodes suspended by the Kymar© rope from a well cap shown in Figure 10. The ropes were tied to a steel rod welded across the top of the opening. Figure 11 shows the complete installation with the anode lead wires running from the well cap through the 2 inch plastic conduit. The figure also shows the excess Kymar© rope sticking out of the top of the well cap. The excess rope was later cut off and the slot in the well cap was sealed with pipeline tape.

The anodes at Little Rock were installed in a similar fashion except at Barksdale LORESCO DW3 © calcined petroleum coke, round grain, passing a No. 16 sieve was pumped from the bottom of the hole to a height of 50 feet above the highest anode but at Little Rock the TA-3 anodes were suspended in the open hole without backfill. The anodes at Little Rock were suspended in the vicinity where original anodes were removed. No vent pipe was used in either well. Figure 12 shows Air Force technicians lowering a TA-3 anode into the well. Figure 13 shows how several workers are needed to keep lead wire and rope from kinking or getting entangled while an anode is being lowered down the well. Figure 14 shows how individual anode support ropes are tied off at the top of the well. The performance of these anode beds will be monitored until failure occurs.

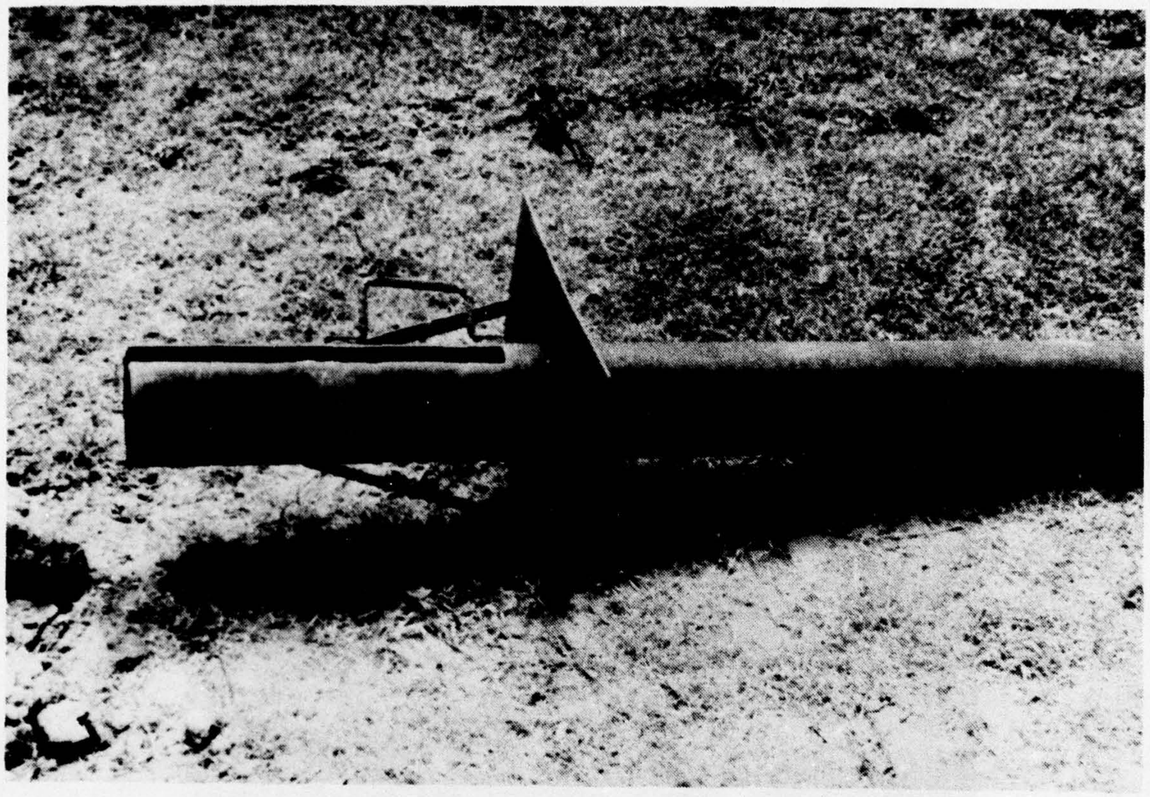

Figure 10. New Well Cap

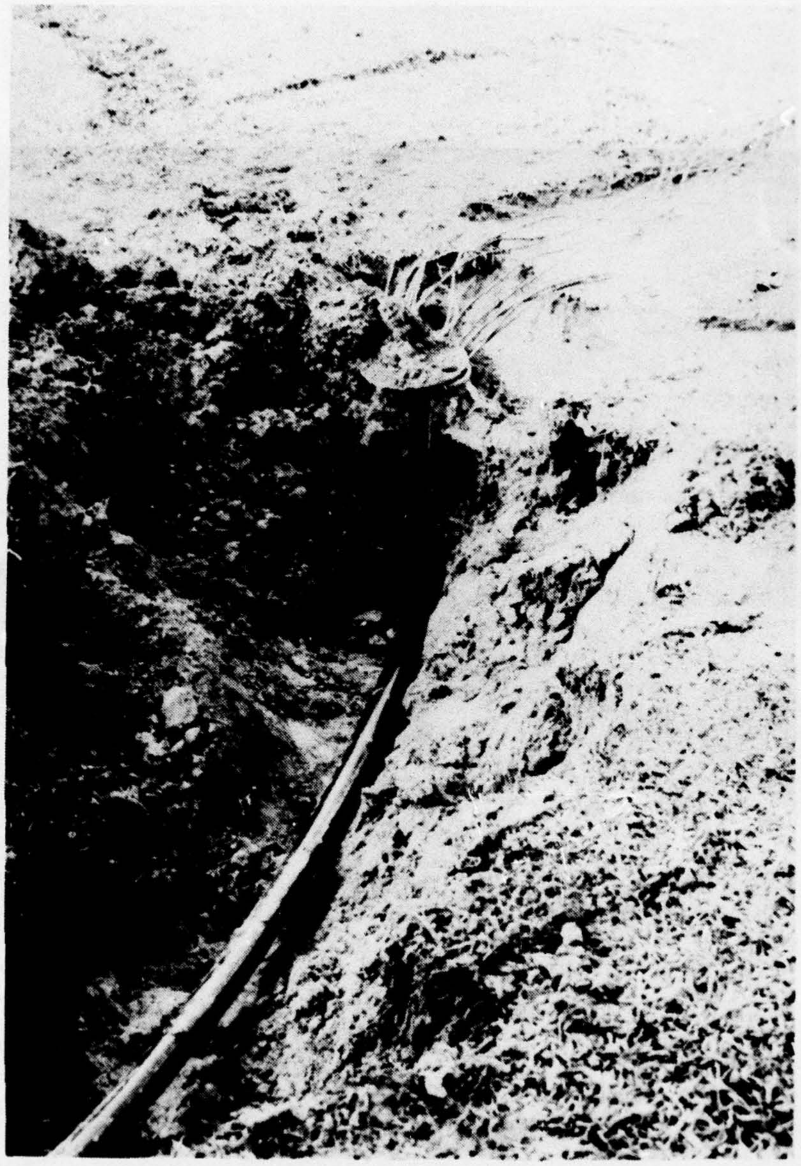

Figure 11. Anode Lead Wires Running From Well Cap

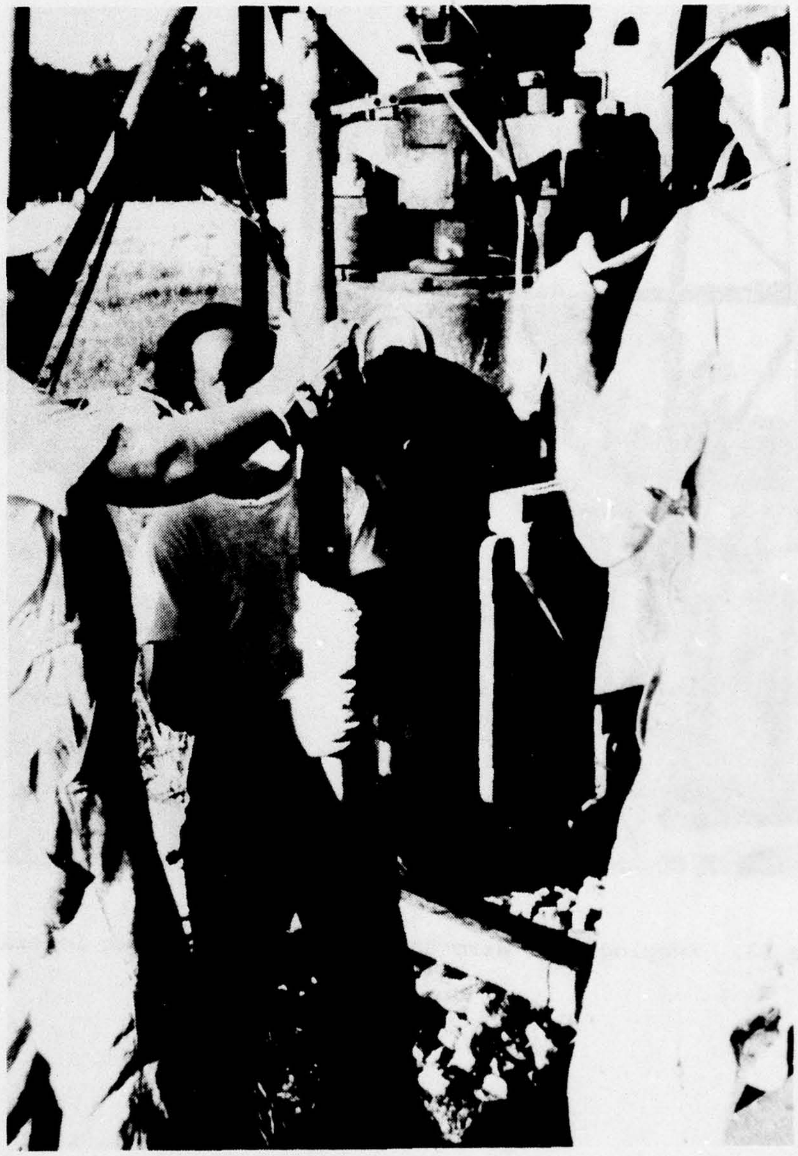

Figure 12. Technicians Lowering a TA-3 Anode Into the Well

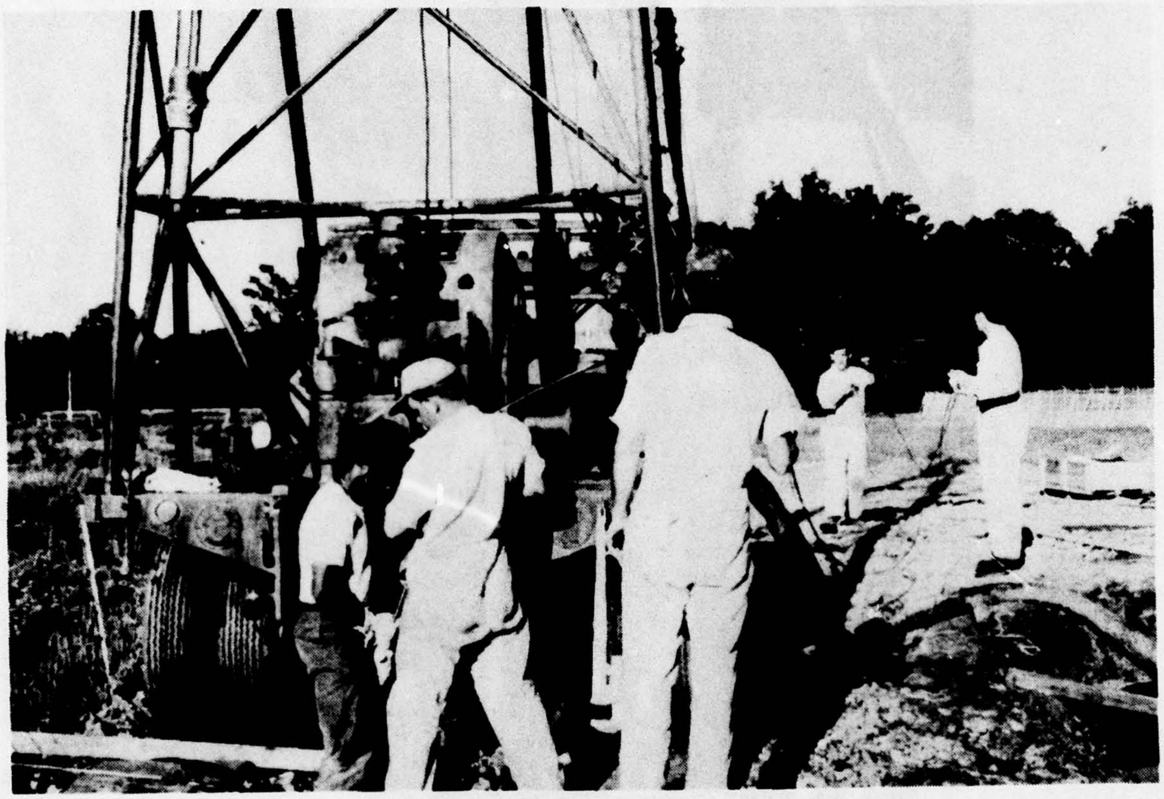

Figure 13. Keeping Lead Wire and Rope Straight While Lowering Anode

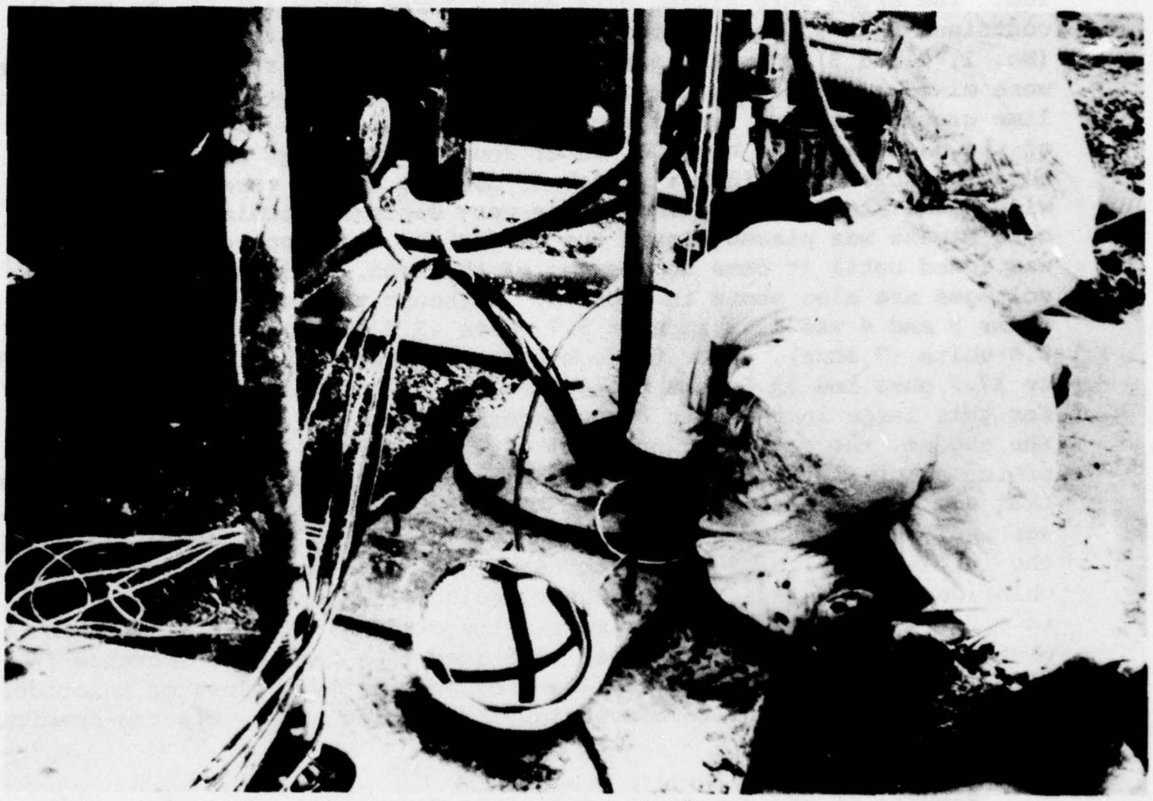

Figure 14. Anode Support Ropes Tied Off at Well Top

SECTION IV

LABORATORY TESTS TO REPRODUCE ANODE OR INSULATION FAILURE IN A DEEP WELL ENVIRONMENT

A. TESTING ANODES WITHIN 55 GALLON DRUMS.

With the intent to capture and analyze electrolyte and gas generated by working anodes, six 55 gallon steel drums were set up in the lab. The drums were filled with sand. Three drums (No. 4, 5, and 6) contained 2" x 9" high silicon cast iron anodes and three drums (No. 1, 2 and 3) 2" x 12" graphite anodes. Three different electrolytes were mixed and added to the drums in order to try to duplicate the high lime ground water of the Midwest; the high chloride, high alkalinity of the West; and the high CO_2 water found in wells at some Air Force bases. Table 4 provides a sketch of how the anodes were installed within the steel drums. The anodes were centered within the drums, coke breeze was placed around the anodes and the prepared electrolyte was added until it came to the top of the sand. Initial currents and voltages are also shown in Table 4. Although the initial current for drums 3 and 4 was 1.79 amps at 5.7 volts (3.2 ohms) and 1.15 amps at 6.9 volts (7 ohms), after three months the circuit resistance increased to 37.7 ohms and 39.5 ohms respectively. There could be two reasons for this large increase in circuit resistance: gas building around the anodes, the cathodes, or both; or an increase in the resistivity of the electrolyte due to loss of chlorides, and other dissolved solids that are converted to gas. After 4 months, the water in barrel No. 4 was analyzed and the chloride content was found to have decreased from the initial level of 3800 ppm to near zero. A quantity of 3800 ppm of chlorides was again added and the circuit resistance went from 50 ohms to 6.8 ohms. This was approximately the original circuit resistance when the test was started. This indicates that the large increase in circuit resistance in drum No. 4 was caused mainly by loss of chlorides in the electrolyte due to conversion to chlorine gas by electro-chemical action at the anode.

Samples of gas generated within the drums were captured in teflon gas bags (Figure 15) and were rushed to the Naval Coastal Systems Laboratory in Panama City, Florida for analysis. Gas samples from the various drums were analyzed in this way on 8 different occasions. A sample analysis is shown in Table 5. The significant findings from these gas analyses were:

1. Nascent oxygen is created at the anode.

2. The electrochemical action attacks the carbon in graphite anodes and in the coke breeze to form various gases (CO_2, CO, CH_4) which can contribute to gas blockage.

TABLE 4. ANODE TESTS USING 55 GALLON DRUMS

DRUM NO.	INITIAL ANODE CURRENT AMPS	INITIAL ANODE VOLTAGE VOLTS	ELECTROLYTE	pH	TYPE ANODE
1	0.785	11	HIGH Co^2	6.9	GRAPHITE
2	0.830	11	HIGH LIME, HIGH SULFATE	7.3	GRAPHITE
3	1.150	6.9	HIGH CHLORIDE	8.3	GRAPHITE
4	1.790	5.7	HIGH CHLORIDE	7.3	HSCBCI
5	0.74	9.5	HIGH LIME, HIGH SULFATE	7.3	HSCBCI
6	0.86	9.5	HIGH Co^2	7.2	HSCBCI

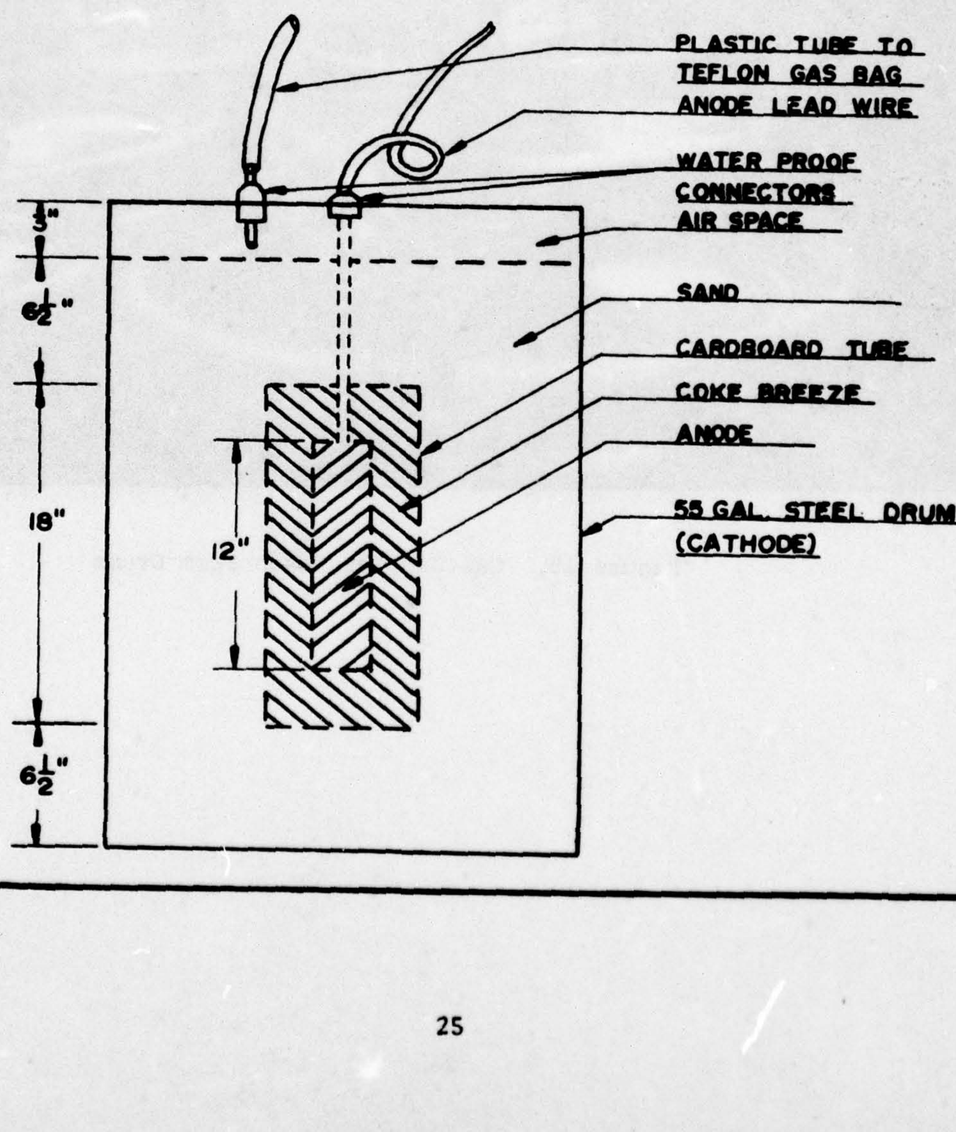

Figure 15. Gas Samples Taken From Drums

TABLE 5. ANALYSIS OF GAS SAMPLES FROM DRUMS 4 AND 6

Item	Sample No. 4	Sample No. 6
O_2	16.80%	9.23%
N_2	19.20%	13.27%
CO_2	3.16%	7.60%
CO	.26%	1.14%
H_2	60.58%	68.75%
H_2S	2 ppm	2 ppm
SO_2	2 ppm	2 ppm
CH_4	108 ppm	307 ppm
C_2H_2	3 ppm	2 ppm
C_2H_6	6 ppm	6 ppm
C_3H_7	.3 ppm	.3 ppm
C_3H_8	1 ppm	.4 ppm
Unknown Hydrocarbon	.3 ppm	-

3. Although not shown in the gas analysis of Table 5, the strong odor of chlorine indicated that chlorides were converted to chlorine gas. The disappearance of chlorides from the electrolyte detected by chemical analysis of the electrolyte verifies this theory. The detection of small amounts of chlorine gas by a gas chromatograph is not likely to occur. Gas blockage within the barrels was a minor problem. After the power had been on a considerable time, it was turned off and the gas released. After being off for 25 days, the power was again turned on and the current measured. The current had increased for each anode an average of only 20 percent. Since considerably more gas was generated at the cathode, the effect of the gas at the anode with respect to anode-to-electrolyte resistance was small. After 345 days drums No. 3 and 4 were opened and after 445 days of operation drums No. 1, 2, 5 and 6 were opened. The anodes were inspected and photographed. Table 6 shows the average current and the total average ampere-hours passed through each anode. Two significant facts were revealed by the inspection:

a. The high molecular weight polyethylene insulation was blistered only on the lead to anode No. 4, a high silicon cast iron anode in high chloride electrolyte. Since anode No. 1 had a higher amp-hours output than anode No. 4 it may be concluded that chlorides are necessary to experience blistering and deterioration of anode lead wire insulation.

b. The high silicon cast iron anodes suffered less weight loss and corrosion damage than the graphite anodes. Condition of anodes after test can be seen in Figure 16 through 19. Figures 16 through 18 show the condition of graphite anodes, whereas Figure 19 shows the condition of the high silicon cast iron anodes.

B. TESTING ANODES WITHIN A PRESSURIZED "W" CELL.

It was recognized that the tests using anodes within the drums had two major drawbacks. They could not be operated at deep well pressure (a 200 foot deep anode in a well full of water would be subjected to 86.7 PSI) and cathode gases were in contact with anode gases. To overcome these drawbacks, a "W" cell was constructed from 4 inch diameter polyvinyl chloride pipe. The "W" cell consisted of 3 vertical columns connected at the bottom by two 4" elbows and a tee (See Figure 20). The electrolyte was common to all columns but gases were separated in that they rose to the top and were trapped within their separate compartments. A graphite anode was hung in the left column, a HSCI anode in the right column, and a piece of steel in the center column for the cathode. All lead wires were insulated with high molecular weight polyethylene. In the first test, glass beads were used as backfill around the anodes to aid in the entrapment of gas around the anode and lead wire. The current to each anode was adjusted to one amp per square

TABLE 6. LABORATORY TEST - ANODES WITHIN 55 GALLON DRUMS

DRUM NO.	TYPE ANODE	ANODE SURFACE AREA (FT^2)	AVERAGE CURRENT OUTPUT (MA)	AVG. ANODE CURRENT DENSITY (A/FT^2)	DURATION OF TEST (HRS)	TOTAL AMP-HRS OUTPUT
1	GRAPHITE	0.52	950	1.8	10680	10146
2	GRAPHITE	0.52	852	1.6	10680	9078
3	GRAPHITE	0.52	752	1.4	8280	6210
4	HSCI	0.319	1100	3.4	8280	9108
5	HSCI	0.319	600	1.8	10680	6408
6	HSCI	0.319	650	2.0	10680	6942

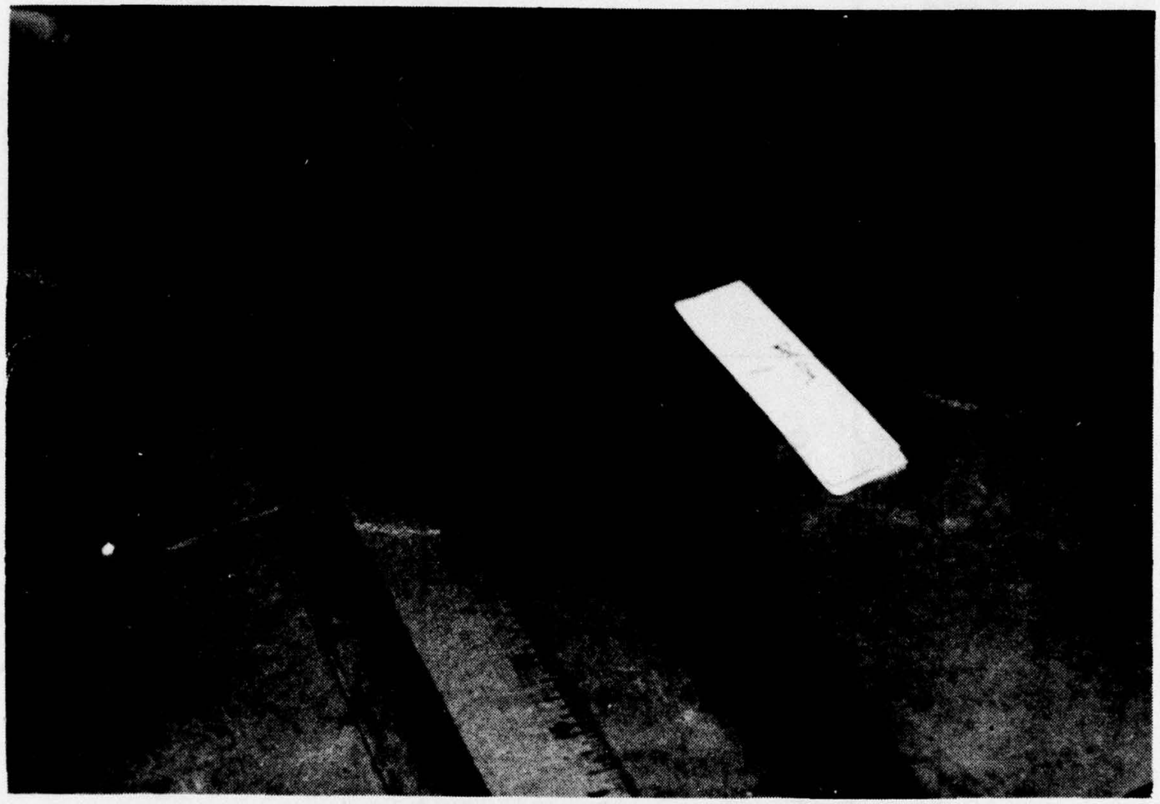

Figure 16. Corrosion Damage to Graphite Anode, Drum 1

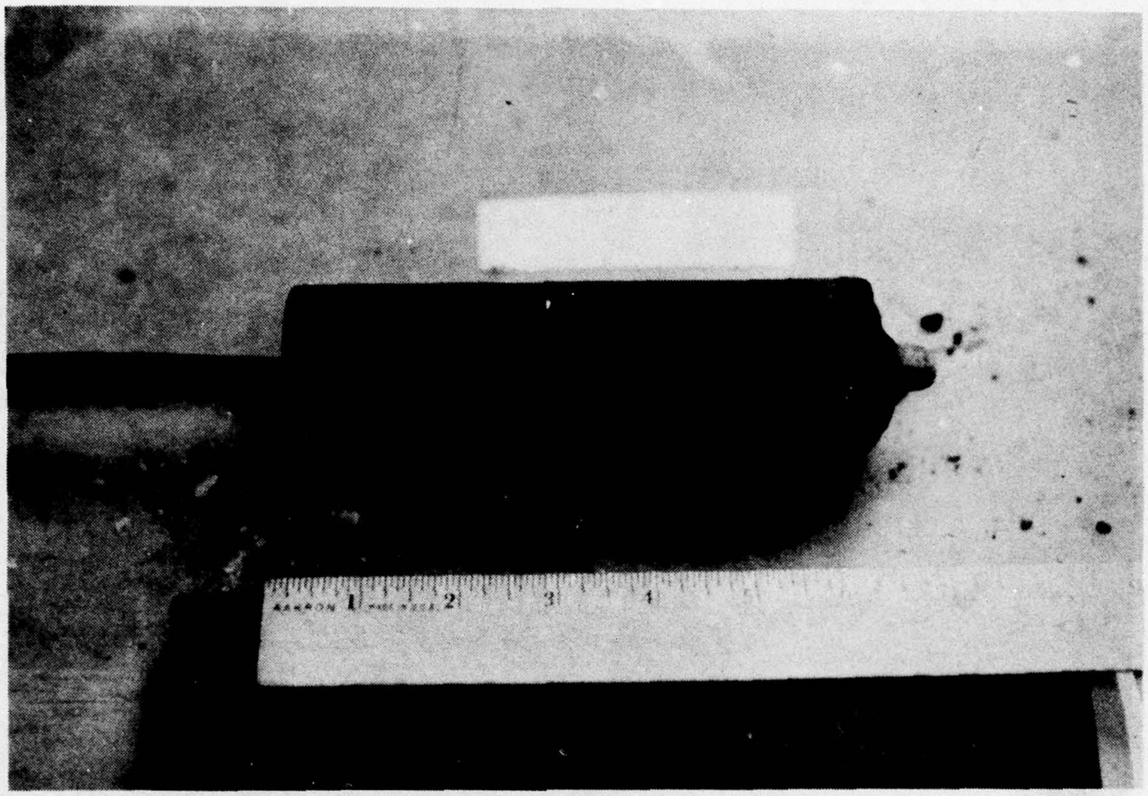

Figure 17. Corrosion Damage to Graphite Anode, Drum 2

Figure 18. Corrosion Damage to Graphite Anode, Drum 3

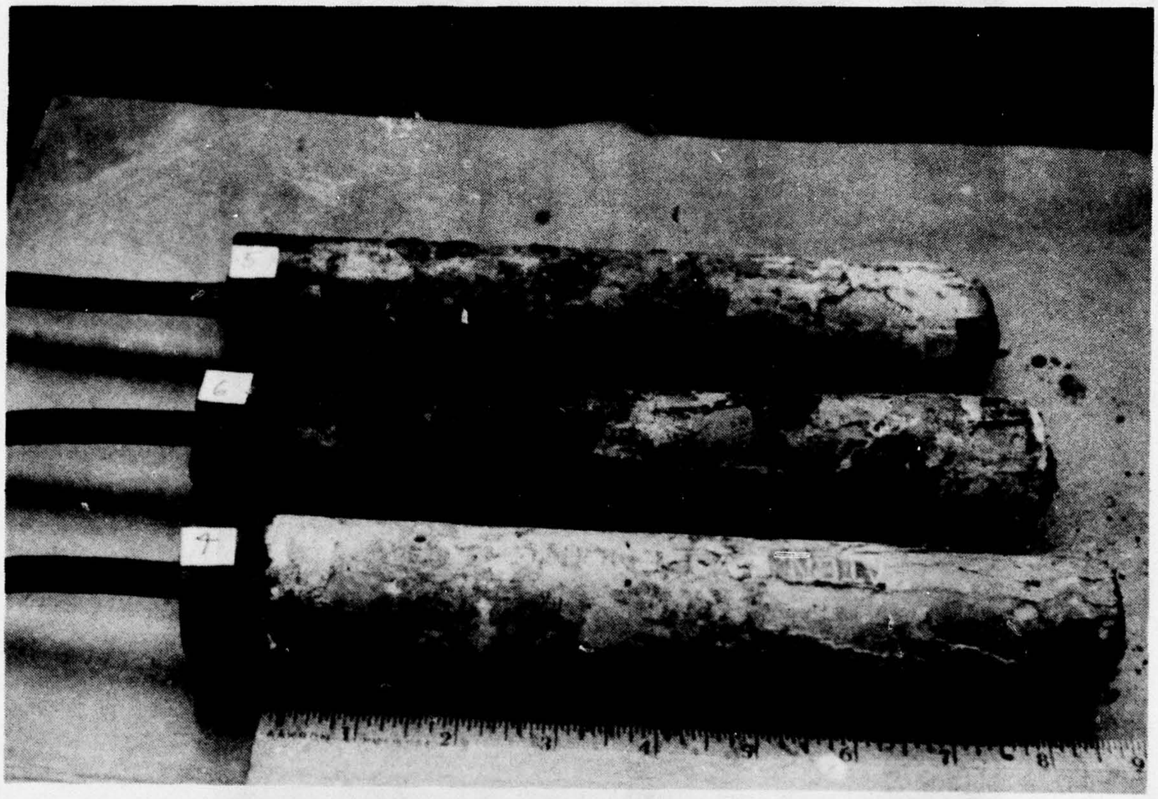

Figure 19. Corrosion Damage to High Silicon Cast Iron Anodes

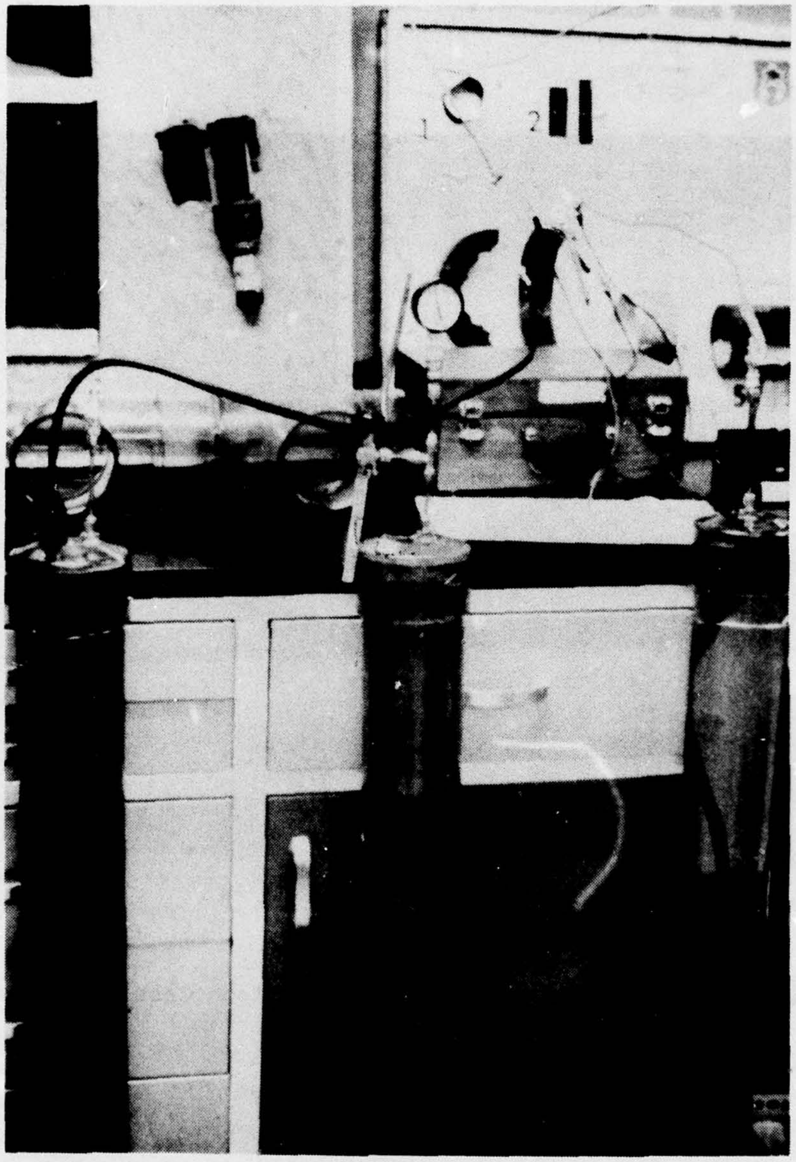

Figure 20. "W" Cell Test Apparatus

foot of anode surface area. The electrolyte added to the cell was a high chloride solution similar to that added to drums 3 and 4. The gases created by the anodes created pressures as high as 90 PSI. Gas samples were captured in teflon bags and were analyzed at the Naval Coastal Systems Laboratory, Panama City FL. The analysis showed that large amounts of nascent oxygen were generated and that larger quantities of CO_2 and CH_4 were generated by the graphite anode indicating deterioration of the graphite (See Table 7). Another finding was that a solution in the bottom of the teflon gas bag that condensed from the gases contained large amounts of chlorides (3,813 PPM). These chlorides must have come from anodegenerated chlorine gas that could not be detected by the gas chromatograph, but was detected by smell.

After 28 days the "W" cell was opened and the glass beads were removed. The pH of the electrolyte in both anode columns was 1.5 and the electrolyte had a strong smell of free chlorine. The HSCI anode was then surrounded with type SW LORESCO© calcined petroleum coke and the graphite anode was surrounded with coal coke breeze, particle size 3/16" and smaller. A plastic mesh was first placed at the bottom of each anode column to contain the coke breeze. The tops of the anode columns were then sealed with a threaded pipe cap to allow access without cutting the PVC pipe. Current was again adjusted to approximately 1 amp/ft^2. Although the graphite anode was larger in size (0.520 ft^2 for graphite versus 0.319 ft^2 for cast iron surface area), the circuit resistance of the cast iron anode was lower than the circuit resistance of the graphite anode (590 MA from the C.I anode versus 440 MA from the graphite anode with the same voltage applied).

After two months the circuit resistance for both anode columns became so high that the required current could not be maintained. Analysis of the electrolyte showed that the chloride content was near zero, so chlorides were added to the electrolyte. The pressure was allowed to go as high as 90 PSI and then bled down to prevent rupture of the pipe columns. The anode current was turned off every weekend for the same reason. After 42 days the columns were opened for inspection. The high molecular weight polyethylene (HMPE) insulation was covered with blisters. The blisters were much more numerous and severe on the lead from the cast iron anode than they were on the graphite anode lead.

Figure 21 shows the blistering damage on the cast iron anode lead taken from the PVC "W" cell containing coke breeze after 42 days of operation. The HMPE insulation also started to turn white similar to the deteriorated insulation retrieved from the well at Barksdale AFB. Figure 22 shows the blisters with greater magnification. True size can be determined by comparing with the magnified lead from a pencil in the upper right corner.

TABLE 7. ANALYSIS OF GASES - ANODES SURROUNDED BY GLASS BEADS

Component	High Silicon Cast Iron Type FC Electrode	Graphite Type QA
H_2	12.78%	29.63%
O_2	78.69%	48.55%
N_2	5.28%	15.44%
CO_2	3.24%	4.88%
CO	.01%	1.51%
CH_4	2.3 ppm	56 ppm

NOTE: About 1 cc of water was removed from the sample, "High Silicon Cast Iron Type FC Electrode", and checked for pH. The solution was found to be very acid with a pH of 2. Also the solution was found to contain 3,813 ppm CL. Indications are that HCL had dissolved in the H_2O.

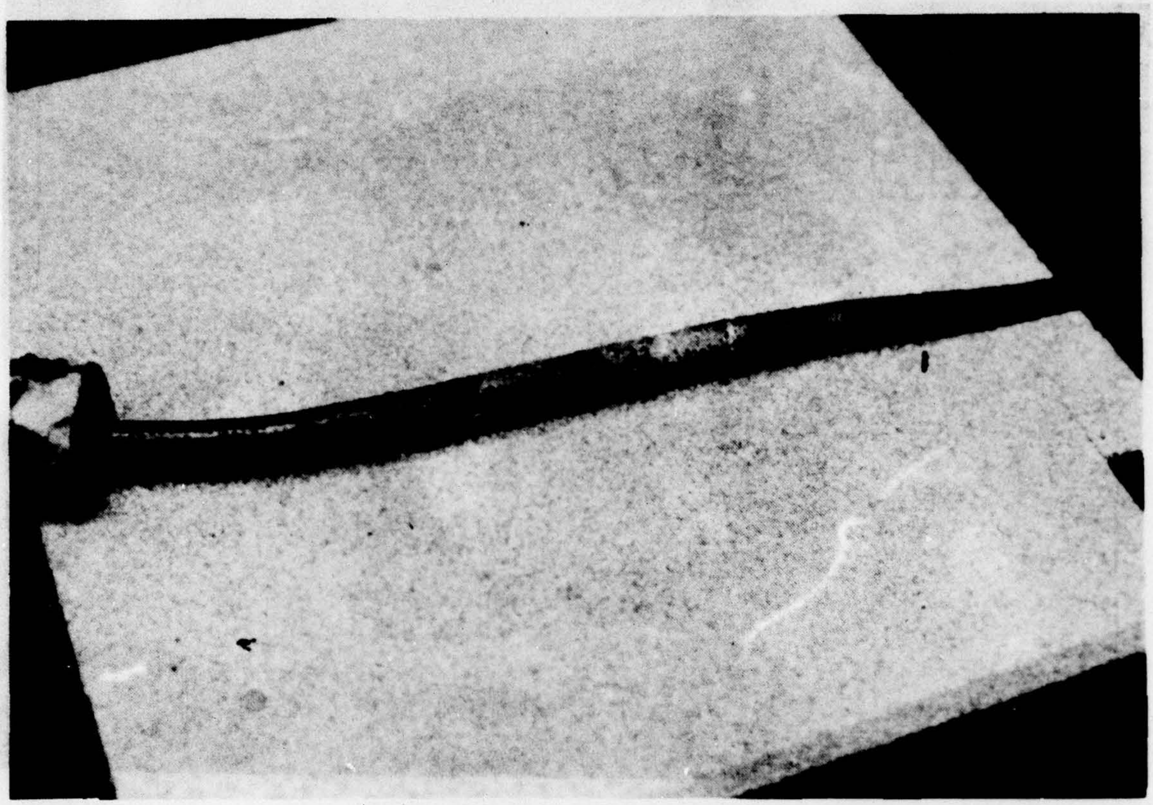

Figure 21. Blistering Damage on Cast Iron Anode Lead

Figure 22. Blistering Damage Magnified

C. PERFORMANCE OF A NEW TYPE OF ANODE LEAD INSULATION

Thus far we have shown that high molecular weight polyethylene insulation will not perform satisfactorily in deep well anode beds containing chlorides. A search of the literature will reveal that other types of insulation will fare no better and in many cases, not as well. More recently, a wire insulation has been advertised by the manufacturer to be superior to other insulations in harsh chemical environments. It has also been learned that this insulation has been made available by the manufacturer of high silicon cast iron anodes as an alternate to HMPE insulation. We obtained one of these HSCI anodes insulated with this new insulation that carried the trade name of HALAR© and is manufactured by Allied Chemical Corp. This anode was installed in a new "U" cell having only one anode column and one cathode column. No coke breeze was used in this cell. The electrolyte added was the same as that in the previous "W" cell. To maintain a constant high pressure (90 PSI), an adjustable air compressor pressure relief valve was installed in each leg of the "U" cell. A piece of HMPE insulated wire was placed in the anode column with the HALAR© but not tied electrically into the anode circuit. The ends of this wire were sealed with epoxy resin to avoid stray current corrosion of the copper wire. This test was run for 42 days and then the cell was opened for inspection. The HALAR© was not affected in any way but the piece of HMPE insulation was blistered to the extent shown in Figure 23.

To determine the long term effect on HALAR© in a deep well environment containing chlorides, the HSCI anode having HALAR© insulated lead wire and the piece of HMPE insulate wire were placed back in the "U" cell and the cell was again operated at 80 to 90 PSI for another 6 months. At the end of the 6 month period the HALAR© was again inspected and found to be in like new condition while the HMPE insulation was blistered more severely than at the end of the 42 day test.

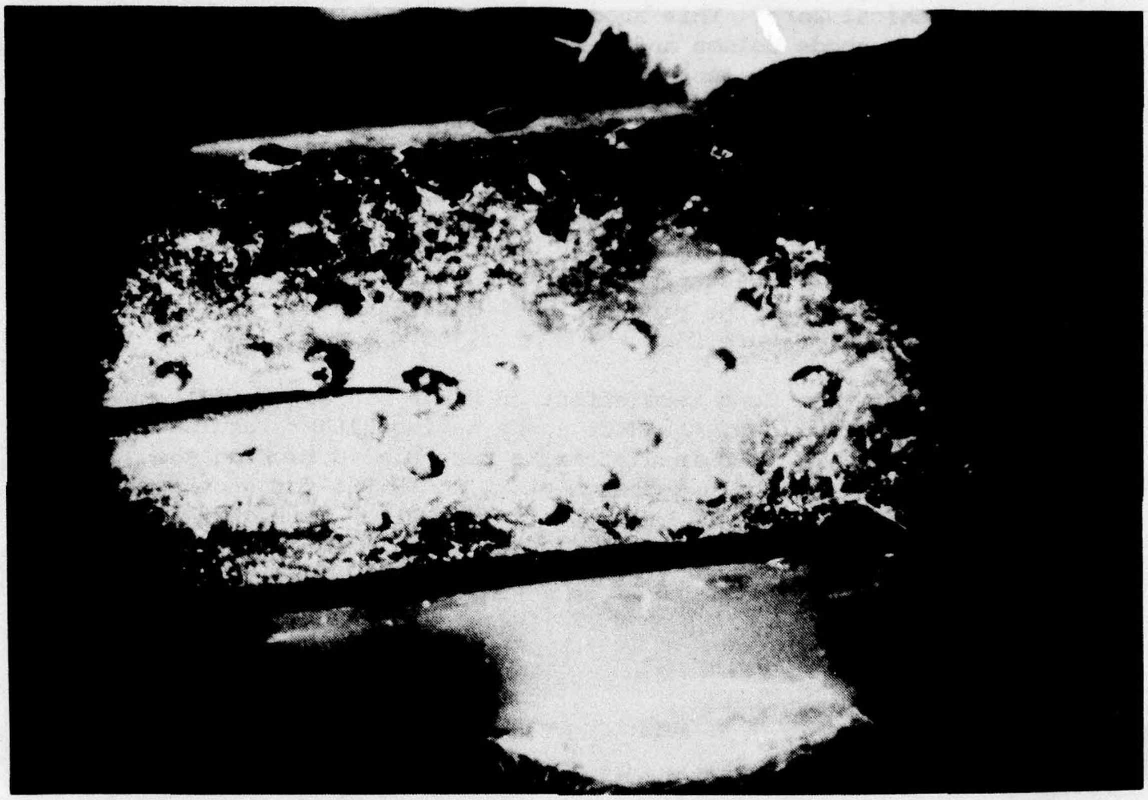

Figure 23. Magnified Blistering Damage on HPME Insulation

SECTION V

RECOMMENDATIONS

The following are recommendations for installing deep well anode beds based on findings of this investigation:

1. Where chlorides are present, HALAR© insulated wire with a HMPE jacket for mechanical protection should be used in place of all HMPE insulation.

2. Vent pipes should not be used unless the minimum particle size of the anode backfill is larger than the holes in the vent pipe.

The following are recommendations for additional research:

1. Monitor the performance of the tubular anodes and the more expensive round particle, calcined petroleums coke (LORESCO DW-3©) over a long period of time.

2. Perform additional investigations on anode gas blockage. It is very difficult to duplicate this in the laboratory because a long column of anodes and anode backfill is needed.

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